

# **Study of Nonlinear Mesoscale Processes: Applications to Lagrangian Data Analysis and Subgrid Scale Parameterization**

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## **LONG TERM GOALS**

The long term goals of this proposal are to advance the understanding of nonlinear processes in ocean dynamics and the development of new methods of investigation and prediction. Special attention is given to transport problems, and specifically to the use of Lagrangian data and to the development of effective subgrid scale parameterizations.

## **OBJECTIVES**

The specific scientific objectives of the work done can be summarized as follows:

- 1) Study of transport in semi-enclosed basins, focusing on the impact of inhomogeneous flows, coastal boundary processes and exchanges with other basins. The problem is attacked both theoretically, using simplified circulation models, and through the analysis of Lagrangian data sets.
- 2) Prediction studies for particle motion at scales of few days to a month, with applications to search of objects lost at sea, floating mines, and ecological problems such as spreading of a pollutant or fish larvae. The study includes the development of optimized methods for the assimilation of Lagrangian data.

## **APPROACH**

The work is based on a probabilistic approach. It involves a combination of analytical, numerical and data processing techniques.

## **WORK COMPLETED**

The theoretical study on transport in semi-enclosed basin has been completed, and the application to a drifter data set (1994-1996) in the Adriatic Sea is near completion. The results are contained in two papers in press and one in preparation.

A methodological study on Lagrangian data assimilation has been completed using simulated data from a primitive equation model. The results are described in a submitted paper.

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## RESULTS

Results have been obtained in collaboration with other scientists in the fields of both physical oceanography and mathematics. The main results can be summarized as follows.

1) Transport in semi-enclosed basins has been characterized analytically and numerically using macroscopic effective quantities such as total tracer amount  $C$  and residence time  $T$  (i.e. average time spent by the tracer in the basin). It has been shown that these quantities can be estimated a-priori using the main flow parameters for a wide range of diffusive and recirculating flows. This work has been performed in collaboration with G. Buffoni (ENEA, Italy) and E. Zambianchi (University of Naples, Italy)

Applications to a drifter data set (Poulain, 1998) in the Adriatic Sea (a semi-enclosed subbasin of the Mediterranean Sea), have been considered (Griffa et al., 1998). Transport properties have been studied using a simplified stochastic model, whose parameters are set using the data. An example of a qualitative comparison between real drifter trajectories and synthetic trajectories computed from the model is shown in Figure 1. More quantitative tests of comparison have been performed, considering statistical quantities and patterns of dispersion. The model appears to reproduce satisfactorily the data characteristics, and it has been used to explore effective transport properties in the basin, such as  $C$  and  $T$ . Also, the model is used for statistical prediction, i.e. to indicate the most likely paths of transport for releases in the basin. These results have been obtained in collaboration with P. Poulain (Monterey PGS) and E. Zambianchi.

2) The prediction of particle motion at scales of the order of days to a month has been studied. It is assumed that Lagrangian data are available in the neighborhood of a targeted particle, and they are used to reconstruct the local velocity field increasing predictability. Technically, this is done assimilating the Lagrangian data into a simplified model for particle motion via Kalman filtering. The method has been successfully tested using synthetic data produced by a primitive equation model. Examples of predictions for various particles in the model interior ocean using various data density are shown in Figure 2. The performance of the prediction scheme has been quantified as function of: a) dynamically different regions; b) density of drifter used in the assimilation; and c) uncertainties in the knowledge of the particle initial conditions and flow parameters. Examples of prediction errors as function of data density in the gyre interior and in the meandering jet are shown in Figure 3. The meandering jet region is characterized by a shorter predictability range, as it can be expected given that it is a highly chaotic region. Theoretical error estimates have been derived, which show a good agreement with the numerical results and which can be used as a-priori estimates for Lagrangian prediction in practical applications. This work has been conducted in collaboration with T. Ozgokmen, the RSMAS post-doctoral fellow supported by this grant, A. Mariano (RSMAS) and L. Piterbarg (USC).

## IMPACT/APPLICATIONS

The results have the potential to impact current studies for a number of problems. From the point of view of transport prediction problems, the results provide theoretical and practical guidance for a wide range of scales. At the mesoscale times (order 1 month) and longer, it has been shown that statistical prediction can be performed using appropriate stochastic models parameterizing particle motion. At

shorter scales (days to month), instantaneous prediction of specific particles can be performed using assimilation of Lagrangian data.

The new techniques to analyze Lagrangian data have the potential to be applied in a variety of situations, including coastal and boundary areas. The theoretical results on transport in semi-enclosed basins can be used as guidance for predicting important macroscopic indicators of mixing.

## **TRANSITIONS**

The new methods for Lagrangian data analysis are presently used in the analysis of a drifter data set in the Adriatic Sea with P. Poulain and E. Zambianchi, and in the comparative analysis of Lagrangian data and simulations in the Atlantic in collaboration with E. Chassignet (RSMAS) and Z. Garaffo (RSMAS).

The results for Lagrangian data assimilation are used for particle prediction studies in the Adriatic Sea and in the Sicily Channel in collaboration with P. Poulain, and it has been used as guidance for a project sponsored by the U.S. Coast Guard for search and rescue problems (with D. Olson (RSMAS) and A. Mariano).

## **RELATED PROJECTS**

Related projects are carried out with other investigators funded by ONR, NSF, NOAA and the European Science Foundation (TAO Project).

Assimilation methods for nonlinear Lagrangian processes and parameterization of turbulent phenomena using stochastic models are studied in collaboration with L. Piterbarg, E. Zambianchi and A. Provenzale (CNR, Italy).

Applications of the new analysis method to Lagrangian data sets and model results are carried out with M. Swenson (NOAA), A. Mariano and E. Chassignet.

Particle cluster studies and the relationship between Eulerian and Lagrangian models is performed in collaboration with E. Zambianchi and G. Buffoni.

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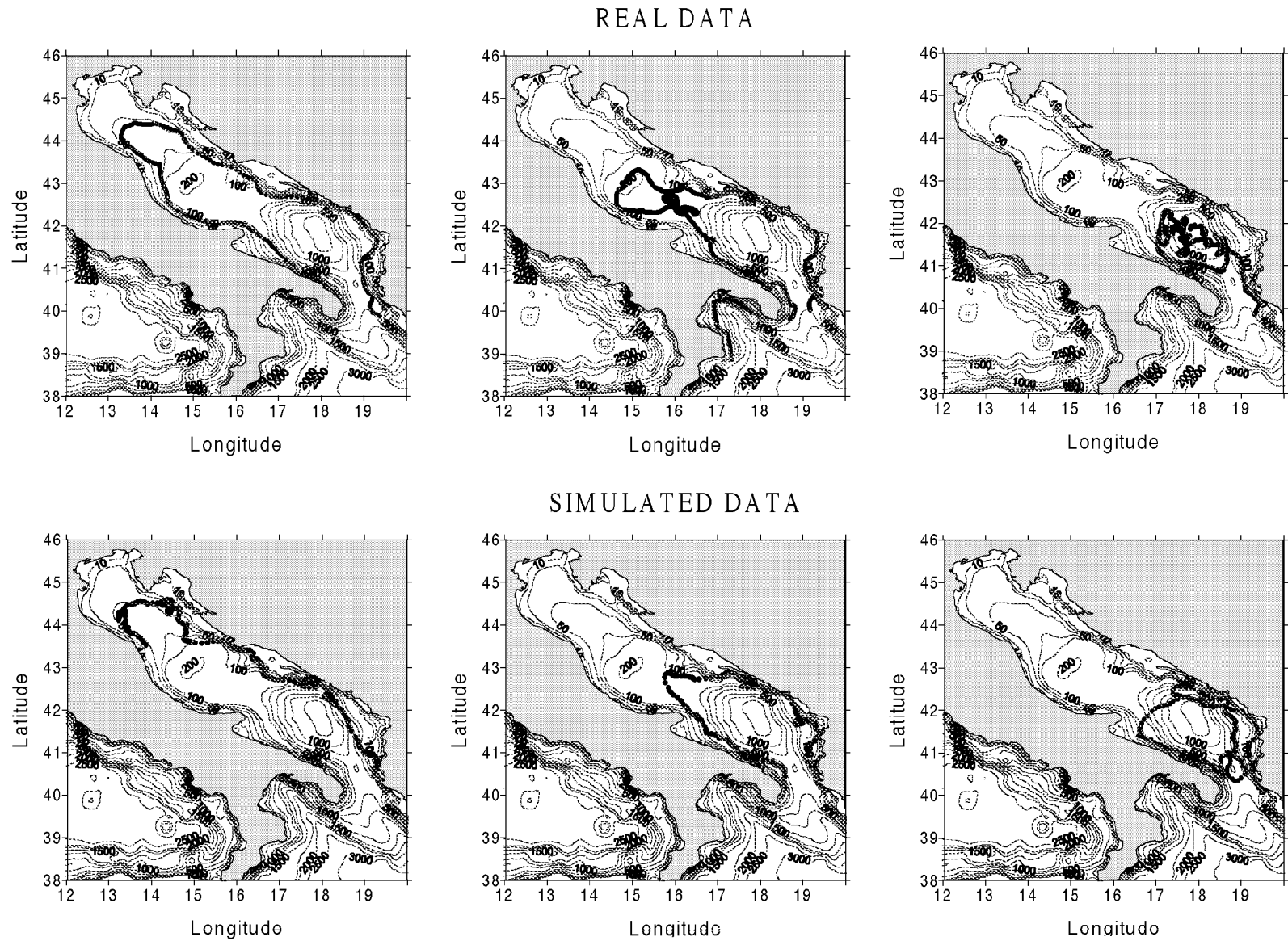
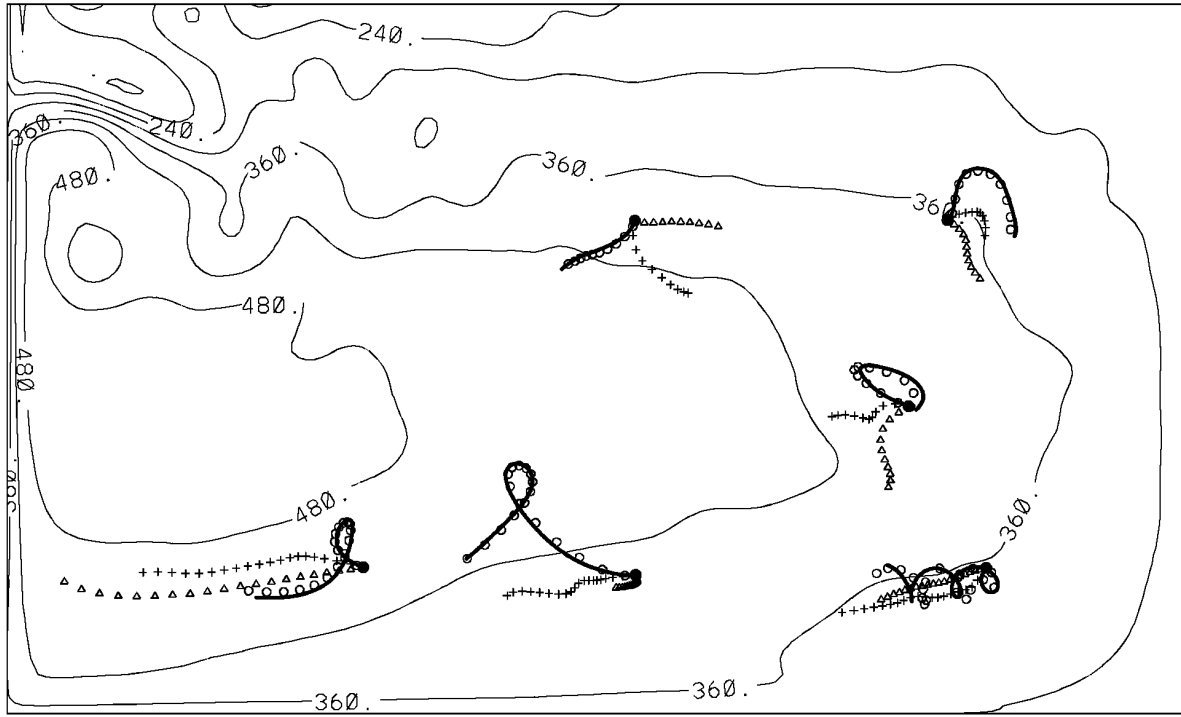


Figure 1: Examples of drifter trajectories (upper panel), and simulated trajectories from the model (lower panel). The model reproduces the various typologies of the real trajectories, with the same statistics.

# Samples of True and Predicted Trajectories



- True trajectory
- △△△△ Mean flow only
- ++++ 1 particle/[2degx2deg]
- oooo 1 particle/[0.25degx0.25deg]

Figure 2: Comparison of true and predicted trajectories for selected particles released in the gyre interior. The solid line indicates the true trajectory, the line composed of triangles indicates the prediction using the mean flow only, plus signs and circles show predicted trajectories with data densities of 1 particle/[2 degree x 2 degree] and 1 particle/[0.25 degree x 0.25 degree], respectively. Note that the accuracy of the predicted trajectories increase with increasing data density. The mean top layer thickness field is plotted in the background (contour interval: 60 m).

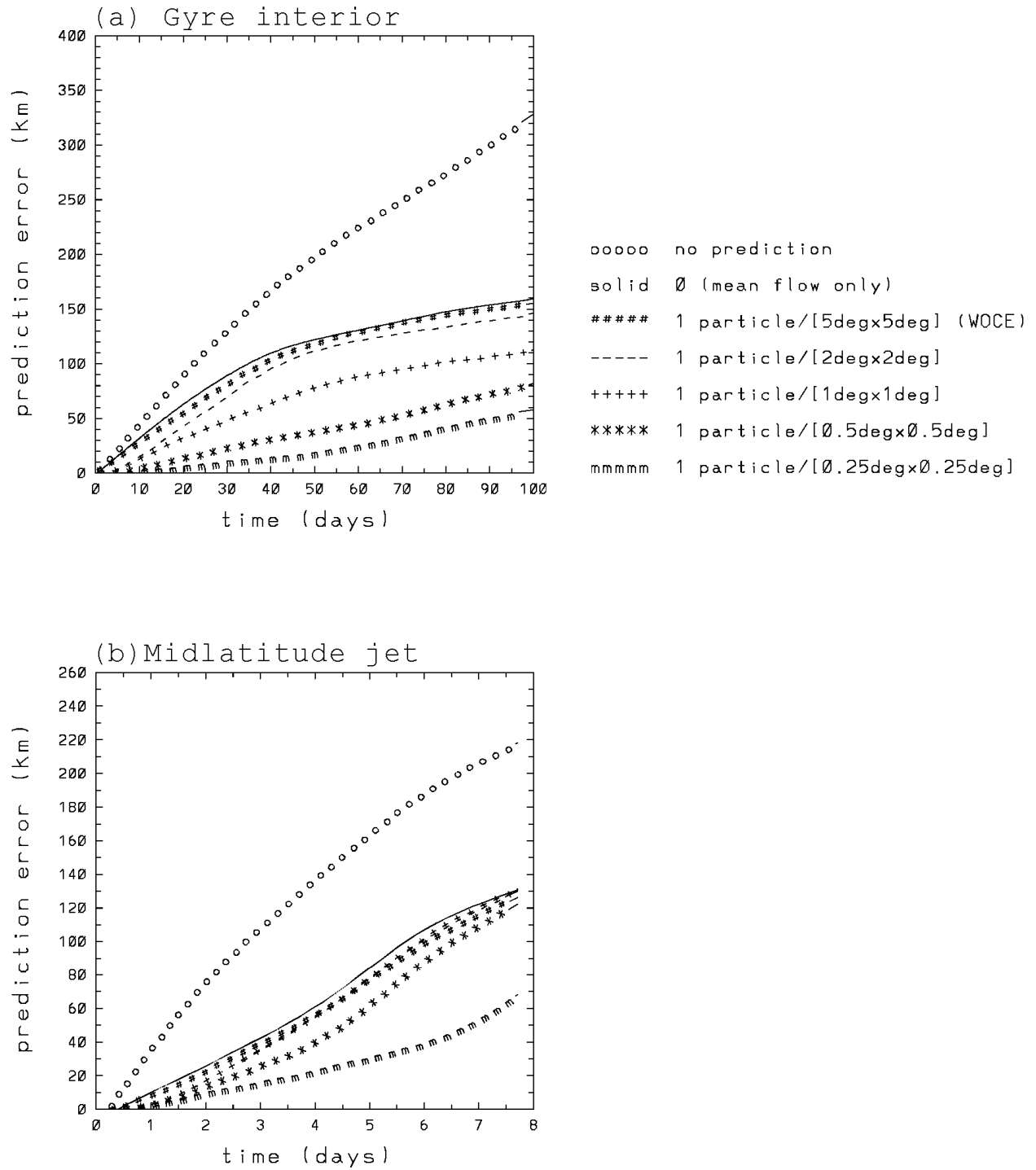


Figure 3: Prediction (rms) error versus time as a function of data density (a) in the gyre interior and (b) in the mid-latitude jet region.